Blasting and erosion wear of wood using sodium bicarbonate and plastic media

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Abstract
The application of sodium bicarbonate (baking soda) and plastic media for blasting and erosion wear of wood is studied. Potential applications of blasting for deburring, cleaning, and weathering (surface texture generation) in the woodworking industry are discussed. A study was conducted on four types of wood using six blasting media in a venturi-type blasting machine to lay out a systematic erosion wear experiment using the plastic and sodium bicarbonate blasting. The particle speed, ranging from 65 m/s to 110 m/s, of the blasting media was measured using the two-disk method. Under the same blasting condition, sodium bicarbonate removed work-material slower than plastic media. The peak erosion wear index was observed at an impact angle in the 30 to 60 degree region.

Blasting is a manufacturing process that uses high-pressure air to carry hard particles to impinge on a workpiece for material removal and surface integrity modification. Erosion wear is the material removal mechanism in blasting. Figure 1 shows the schematic diagram of a venturi-type blasting machine and its accessories. The compressor supplies the high-pressure air stored in an accumulator. A control valve regulates the pressure and the volumetric flow of air into the blasting gun. The airflow creates a suction force that draws the blasting media, via a venturi, into the mixing chamber in the blasting gun. The blasting media mix with air in the chamber, passes through the nozzle, impinges on the workpiece surface, removes or weakens a small amount of work-material, and returns to a recclaimer. The debris, which is usually small and may remain airborne, is removed by a filter. This blasting process is used extensively in shot peening to generate a thin layer of compressive residual stress on the surface of mechanical components, such as springs and gears, and to improve the fatigue properties and stress-corrosion resistance (Guilemany et al. 1996).

In recent years, applications of the blasting process have diversified extensively. For example, plastic and wheat starch blasting has been used in aircraft de-painting applications (Abbott 1996, Djurovic et al. 1999). This process is especially beneficial for delicate composite surfaces and can eliminate the use of chemical solvents, which emit environmentally hazardous volatile organic compounds. Other blasting applications include the cleaning of deposits in gas turbine components using glass and stainless steel blasting media (Raykowski et al. 2001), glass bead blasting of substrates to improve the strength of tool coating (Bouzakis et al. 2001), and cleaning of electrical discharge machining re-cut layers (Qu et al. 2004). This study searches the suitable media, identifies potential applications, and investigates erosion wear characteristics for blasting of wood.

The erosion wear index, \( e \), which is defined as the weight of material removed divided by the weight of media blasted, has widely been used to characterize the material removal rate in blasting. In the past, as shown in Figure 2, researchers have observed that the erosion wear index peaks at different impact angles for ductile metals and brittle solids (Williams 1994). For wood material, the erosion wear data and textures generated on blasted surface are not available. One

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of the goals of this research was to generate the erosion wear index vs. impact angle curves for different types of wood. Another goal was to explore potential applications of the blasting process in the woodworking industry.

A survey was conducted with the woodworking industry, particularly the furniture manufacturing companies, to study potential applications of wood blasting. This study identified three potential applications: 1) deburring; 2) cleaning; and 3) weathering and surface texture generation.

**Deburring**

Wood is a fibrous material. Burrs are commonly generated on machined surfaces. Figures 3a and 3c show examples of burrs created on surfaces of furniture parts produced by a computer numerical control (CNC) carving machine. It is difficult to totally eliminate burr formation in wood machining operations due to the gradual wear of the sharp, rotating carving tools and the nature of wood material. Typical length of the burr in Figure 3 is about 1 to 4 mm. To remove these burrs, labor-intensive manual sanding is used in the production of furniture and wood products to deburr and clean surface features on machine-carved parts. Blasting by sodium bicarbonate, as shown in Figure 3b, has demonstrated effective removal of burrs without dis-coloring or significantly weathering the wood surface. Weathering, as shown in Figure 3d, is the exposure of hard annual rings (latewood) and generation of surface texture. During blasting, the earlywood or soft layers between annual rings is removed at a faster rate. Weathering is more prominent at higher air pressure (0.48 MPa) and longer blasting time, as can be seen by comparing Figures 3b and 3d. A blasting nozzle can be integrated in CNC carving machines to run the wood blasting deburring in-situ close to the rotating tool in the finishing carving path. This set-up can enable automatic deburring using blasting in wood carving operations.

**Cleaning**

Figure 4 shows another application of blasting to remove the black surface layer in laser-cut wood parts. A laser can flexibly and effectively cut wood with intricate geometries. After laser cutting, as shown in Figure 4a, the surface is black due to burning. Manual sanding is the current practice to remove the black layer. The plastic media blasting was tested for removal of the burned layer. As shown in Figures 4b and 4c, the original wood surface texture was restored. Figure 4c also shows that the blasting process is especially effective in cleaning difficult-to-reach areas.
Table 1.—Summary of commercially available blasting media (in ascending order of hardness).

<table>
<thead>
<tr>
<th>Blasting media</th>
<th>Hardness (mohs)</th>
<th>Specific gravity</th>
<th>Typical cost ($/kg)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn cob</td>
<td>2.0 to 2.5</td>
<td>1.2</td>
<td>0.7</td>
<td>By-product</td>
</tr>
<tr>
<td>Sodium bicarbonate</td>
<td>2.8</td>
<td>2.2</td>
<td>1.1</td>
<td>Natural</td>
</tr>
<tr>
<td>(baking soda)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walnut shell</td>
<td>2.5 to 3.0</td>
<td>1.3</td>
<td>0.9</td>
<td>By-product</td>
</tr>
<tr>
<td>Pecan shell</td>
<td>2.5 to 3.0</td>
<td>1.3</td>
<td>0.9</td>
<td>By-product</td>
</tr>
<tr>
<td>Apricot shell</td>
<td>3.0 to 4.0</td>
<td>1.4</td>
<td>0.9</td>
<td>By-product</td>
</tr>
<tr>
<td>Corn hybrid polymer</td>
<td>3.2</td>
<td>1.5</td>
<td>3.3</td>
<td>Manufactured</td>
</tr>
<tr>
<td>Wheat starch</td>
<td>3.2</td>
<td>1.5</td>
<td>3.3</td>
<td>Manufactured</td>
</tr>
<tr>
<td>Plastic: Type I polyester</td>
<td>3.0</td>
<td>1.3</td>
<td>3.3</td>
<td>Manufactured</td>
</tr>
<tr>
<td>Type VI clear-cut</td>
<td>3.0</td>
<td>1.3</td>
<td>3.3</td>
<td>Manufactured</td>
</tr>
<tr>
<td>Type V acrylic</td>
<td>3.3</td>
<td>1.2</td>
<td>3.3</td>
<td>Manufactured</td>
</tr>
<tr>
<td>Type II urea*</td>
<td>3.5</td>
<td>1.5</td>
<td>3.3</td>
<td>Manufactured</td>
</tr>
<tr>
<td>Type III melamine</td>
<td>4.0</td>
<td>1.5</td>
<td>3.3</td>
<td>Manufactured</td>
</tr>
<tr>
<td>Steel/cast iron beads</td>
<td>5.0</td>
<td>7.8</td>
<td>0.4</td>
<td>Manufactured</td>
</tr>
<tr>
<td>Glass beads</td>
<td>7.0</td>
<td>2.3</td>
<td>0.9</td>
<td>Manufactured</td>
</tr>
<tr>
<td>Silica sand/garnet</td>
<td>7.0</td>
<td>2.2</td>
<td>0.2</td>
<td>Natural</td>
</tr>
<tr>
<td>Aluminum oxide</td>
<td>9.0</td>
<td>3.9</td>
<td>0.9</td>
<td>Manufactured</td>
</tr>
<tr>
<td>Silicon carbide</td>
<td>9.5</td>
<td>3.1</td>
<td>1.0</td>
<td>Manufactured</td>
</tr>
<tr>
<td>Diamond</td>
<td>10</td>
<td>3.5</td>
<td>3300</td>
<td>Manufactured</td>
</tr>
</tbody>
</table>

*Media used in the wood erosion wear study.

Figure 4.—Application of plastic media blasting to remove burned black surface layers on a laser-cut furniture part.

Weathering and surface texture generation

Blasting can be used to weather a special surface texture on wood. Figure 3d shows the weathered surface generated by sodium bicarbonate blasting at high pressure for 10 seconds. Instead of using nature to weather a wood surface, blasting can shorten the weathering time for wood surface texture generation.

In this paper, the selection of blasting media and potential applications of wood blasting are first introduced. The particle speed measurement and set-up of an erosion wear experiment are then presented. Results of the erosion wear index for blasting of pine and oak using sodium bicarbonate and plastic media are also discussed.

Selection of blasting media for wood blasting

Table 1 lists a wide selection of different types of commercially available blasting media, arranged in order from the soft corn cob to the hard diamond. In addition to hardness, other parameters, such as particle size, shape, toughness, and kinetic energy, also affect the performance of blasting media to achieve the desired material removal rate and surface texture (Feng and Ball 1999). Table 1 also shows the density and typical cost of blasting media and indicates source (natural, manufactured, or by-product).

A preliminary study was conducted on four types of wood: white oak (Quercus alba L.), eastern white pine (Pinus strobus L.), black cherry (Prunus serotina Ehrh.), and sugar maple (Acer saccharum M.). Six types of blasting media were explored: 1) sodium bicarbonate; 2) walnut shell; 3) plastic Type II (urea); 4) plastic Type V (acrylic); 5) aluminum oxide; and 6) silicon carbide.

Test results showed the black cherry and sugar maple had slower erosion wear rates than white oak and eastern white pine. The white oak and eastern white pine, denoted hereafter as oak and pine, respectively, were further studied in an experiment to systematically measure their erosion wear index at different blasting set-ups. Test results also showed that aluminum oxide and silicon carbide generated discoloring on blasted wood surfaces due to the penetration and retention of the hard erodent on the surface. Cleaning by high-pressure air jet was not able to remove the penetrated particles. Aluminum oxide and silicon carbide also exhibited high erosion wear rates, which, depending on the application, might or might not be beneficial. On the contrary, the walnut shell blasting exhibited a very slow erosion wear rate even at the high air pressure setting. The plastic, both Type II urea and Type V acrylic, and sodium bicarbonate exhibited good flexibility in wood blasting, achieving different levels of erosion wear rate by adjusting process parameters.

Based on these experimental observations, two blasting media, the 30/40 ANSI mesh (602 mm average size) Type II urea plastic and 40/50 ANSI mesh (427 mm average size) sodium bicarbonate, were selected for a comprehensive erosion wear experiment. Scanning electron microscopy (SEM) micrographs of the plastic blasting and sodium bicarbonate media at two levels of magnification are shown in Figures 5 and 6, respectively. Both media have been used for wood blasting. Figure 5 illustrates that the particle of original angular plate shape plastic media has edges rounded by blasting. The sodium bicarbonate in Figure 6 has a smaller size and a different, more rounded morphology.

Wood erosion wear experiment set-up

The wood erosion wear experiment was conducted in a Mangum blasting machine manufactured by Hess & Associates, Inc. The machine used a venturi-type blasting gun with a 6.35-mm inner diameter nozzle made of aluminum oxide. Since the media used in this study were relatively soft, nozzle wear was not...
Figure 5. — SEM micrographs of 30/40 ANSI mesh plastic (Type II urea) medium after wood blasting.

Figure 6. — SEM micrographs of 40/50 ANSI mesh sodium bicarbonate medium after blasting.

Table 2. — Process parameters and design of experiment in wood erosion wear.

<table>
<thead>
<tr>
<th>Process parameters</th>
<th>Oak and pine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of wood</td>
<td>Along and 90 degrees across the media stream</td>
</tr>
<tr>
<td>Annual ring orientation</td>
<td>Sodium bicarbonate and plastic (Type II urea)</td>
</tr>
<tr>
<td>Blasting media</td>
<td>0.35 and 0.48 MPa</td>
</tr>
<tr>
<td>Air pressure (MPa)</td>
<td>10, 20, 30, 40, 50, 60, 70, 80, and 90</td>
</tr>
<tr>
<td>Impact angle (degrees)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7. — Experimental set-up for wood erosion wear tests.

A problem. A timing device was added to the standard blasting machine to control the duration of blasting, which was set to 7.5 seconds for all wood erosion wear tests.

The set-up of the erosion wear experiment is shown in Figure 7. The blasting gun is fixed on a holder. The wood workpiece was clamped on a fixture allowing for the change of workpiece orientation in order to achieve different impact angles. The distance between the tip of the nozzle and the workpiece, along the ideal centerline of blasting, was 100 mm. The before and after blasting weight of the workpiece was measured using a precision scale. The weight of the work-material removed during blasting was then calculated. A filter bag was used to catch the media blasted. The before and after blasting weight of the filter bag was measured to find the weight of the media blasted. The weight of the work-material removed was divided by the weight of the media blasted to calculate the erosion wear index, $e$.

Wood is an anisotropic material and the orientation of the annual rings may affect the blasting results. As summarized in Table 2, five process parameters were selected in the wood erosion wear experiment. These parameters included:

- Two annual ring orientations: along and 90 degrees across the direction of media stream;
- Two types of blasting media: sodium bicarbonate and plastic Type II urea;
- Two levels of air pressure: 0.35 and 0.48 MPa;
- Nine impact angles: 10 to 90 degrees in 10-degree increment.

Three repeated erosion wear tests were performed for each test condition. In summary, $432 = 2 \times 2 \times 2 \times 9 \times 3$ blasting tests were carried out in this wood erosion wear test.

Depending on the design of the blasting gun and machine, the same air pressure setting in different blasting machines may result in dissimilar particle speeds and blasting results. The accurate measurement of particle speed can ensure the repeatability of a blasting process in future applications. It can also help to understand the effects of air pressure and types of media on the particle speed. In this study, a device using the two-disk method (Ruff and Ives 1975), as illustrated in Figure 8a, was built and applied to measure the speed of blasting media. This method used two co-rotational disks with a thin slot in the front disk. Two marks were blasted in the back disk, one when the two disks were stationary and another when two disks were rotating at a constant speed. The distance between two disks (20 mm in the apparatus used in this study), the disks’ rotational speed, and the angle between two blasted marks on the back disk are three parameters required to estimate the particle speed.

Figure 8b shows the measured particle speed of the sodium bicarbonate and plastic media used in this study at six air pressures. The larger and lower density plastic medium has a faster particle speed than the sodium bicarbonate under the same air pressure. The particle speed is roughly 80 m/s and 65 m/s at 0.35 MPa and 110 m/s and 100 m/s at 0.48 MPa for plastic and sodium bicarbonate, respectively. These measured particle speeds are comparable to those reported in other research (Ruff and Ives 1975, Qu et al. 2004).

Experimental results and discussion of wood erosion wear

Figure 9 shows the sample blasted surfaces of pine and oak. The weather-
Results of the erosion wear index, \( e \), are shown in Figures 10 and 11 for the oak and pine, respectively. Results of the erosion wear index can be used to select media and process parameters for wood blasting. For example, if the application is deburring, the process with a low erosion wear index and good capability to remove the burr is desirable. If the application is weathering, a good erosion wear index is beneficial.

Two rows and two columns in Figures 10 and 11 represent tests at different air pressures and annual ring orientations, respectively. Data points from three sodium bicarbonate blasting tests are represented by the open square, triangle, and circle symbols. The thin line represents the average erosion wear index of three sodium bicarbonate blasting tests at different impact angles. Similarly, data points from three plastic blasting tests are marked by three different cross symbols. A thick line connects the average erosion wear index of three plastic blasting tests at different impact angles.

Wood is not a uniform, homogeneous material. Many other factors, such as moisture level, different cross-section cuts, variation of species, etc., can change the erosion wear index. As shown in Figures 10 and 11, there are significant variations among the three data points of the erosion wear index under the same blasting set-up. The average of these three data points, represented by the thin and thick lines, are compared and used to distinguish effects of five wood blasting process parameters, listed in Table 2.

**Effect of blasting media.** — Experimental results for both oak and pine show that plastic media generate a larger erosion wear index or higher material removal rate than sodium bicarbonate. The effect of blasting media is not obvious at low (10- and 20-degree) impact angles, low air pressure, and along the annual ring blasting conditions.

**Effect of impact angle.** — At the 10- and 20-degree shallow impact angles, the erosion wear index is typically low. In general, for both pine and oak, the erosion wear index vs. impact angles peaks in the 30- to 60-degree region and then remains flat or slightly reduces at higher impact angles. None of the test curves show blasting at 90 degrees has the maximum erosion wear index which, as shown in Figure 2, is commonly observed in erosion wear of brittle metals. This pattern of erosion wear index vs. impact angle is similar to that observed in erosion wear of steel-ceramic composites (Morrison et al. 1994). Both peaks of brittle solids and ductile metals in Figure 2 contribute to the overall erosion wear behavior of the material and generate a rather flat or slightly decreasing erosion wear rate vs. impact angle after peaking in the 30- to 60-degree region.
is observed in both oak and pine blasting.

Concluding remarks

Experimental results of blasting and erosion wear index for pine and oak using the plastic and sodium bicarbonate media were presented. Five blasting process parameters were varied and their effects on erosion wear index were investigated. The approach proposed in this research has three potential applications in the woodworking industry, including deburring, cleaning, and weathering (surface texture generation). The future research directions include characterization of the burrs in machined wood surfaces and the quantification of weathered or textured wood surfaces after blasting.

Literature cited


